ENDGAME IN THE PACIFIC: COMPLEXITY, STRATEGY AND THE B-29

A MONOGRAPH
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ABSTRACT

ENDGAME IN THE PACIFIC: COMPLEXITY, STRATEGY, AND THE B-29 by MAJ G. Scott Gorman, USAF, 60 pages.

War is the outward expression of competition between complex adaptive political and military systems. In war, competing systems introduce new technological means to gain comparative advantage over other systems and the environment. Greater technological complexity, however, creates greater uncertainty. This uncertainty is the result not only of technical problems associated with new military machines, but also of unintended consequences of technology within the chaotic environment of war. To cope with this increased uncertainty, military strategy should be adaptive in applying new means to achieve desired ends in war. Increased uncertainty demands technological and operational adaptation to achieve desired military objectives.

The United States faced a complex strategic problem in the last years of the war against Japan in the Pacific. The Boeing B-29 Superfortress was the U.S. Army Air Force's technological solution to crossing the vast expanse of ocean to compel the unconditional surrender of Japan with a minimum of American casualties. The B-29's pressurized cockpit, longer range, more accurate bombing systems, and mechanically controlled defensive systems represented a vast improvement over earlier strategic bombardment technology. Army Air Force planners envisioned a high altitude, precision strategic bombardment campaign that would compel the Japanese to surrender unconditionally. The application of the B-29 in the Pacific, however, was not as mechanistically simple as planners had hoped. Under the inevitable stress of war, there were innumerable uncertainties and unintended consequences involved in its employment.

To overcome these uncertainties, planners and operators necessarily had to be adaptive in their application of the B-29 as a technological instrument. From the first operational use of the B-29 in the summer of 1944 to the end of the war, adaptation included mechanical upgrades, changes in tactical methods, and changes in operational objectives. In the end, airmen flew the B-29 not as a high altitude precision bomber as intended, but as a low altitude area bomber dropping incendiaries to burn out Japanese cities. Thanks to the dedicated efforts of both military and civilian personnel associated with the development of the B-29, American adaptation successfully outpaced the increased complexity and uncertainty introduced the bomber's employment.

War is full of uncertainty that requires adaptation to overcome. This monograph presents not only the positive example of successful American adaptation, but also the negative example of the lack of Japanese defensive adaptation. Given the costs and consequences of modern military technology, the case study of the the B-29 in the Pacific theater during World War II holds valuable lessons for future military planners.

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Introduction

War is the outward expression of competition between complex adaptive political and military systems.[1] These systems are complex not only because they contain a great number of parts, but also because of the intricate relationships among these parts, the system itself, and the external environment.[2] War, as a result of this inherent complexity, is uncertain and chaotic. This uncertainty arises from the characteristic of non-linearity in war.[3] Like the proverbial flapping of a butterfly's wings that results in a thunderstorm, small changes to initial conditions in war can have disproportionately greater effects.[4] The living and adaptive nature of opponents is another source of uncertainty in war. War, in sum, is not clockwork, but an organic interaction between competing complex adaptive systems.

Strategy is a plan of action to negotiate complexity and uncertainty to achieve a specific goal.[5] Strategy provides unifying direction, a common purpose for actions within the system. Strategy maps out the employment of means to achieve desired objectives. Unlike mathematical or mechanical solutions, military strategy is aimed at a moving target, an intelligent and adapting opponent. Strategy, given the uncertain and changing nature of war, must similarly be flexible and adaptive to achieve desired endstates.

Theater military strategy employs various tools and methods to achieve desired endstates. Technology, the fashioning of the implements of war through the scientific method, is one tool available to the military strategist.[6] In war, competing systems introduce new technology in an attempt to gain comparative advantage over other systems and the environment. Just as with other inputs within a system, the impacts of

technological change are difficult to predict, often resulting in non-linear effects and unintended consequences. Thanks to the profoundly interactive nature of war, technological tools intended to simplify and solve complex problems may in fact foster additional complexity.

In their competition with the Japanese system in the Pacific theater in 1944, the American military system faced the complex strategic problem of ending the war unconditionally while minimizing American casualties. The Boeing B-29 Superfortress was the U.S. Army Air Force's technological solution to this complex strategic problem. The B-29's pressurized cockpit, longer range, more accurate bombing systems, and mechanically controlled defensive systems represented a vast improvement over earlier strategic bombardment technology. Uncertainty, unintended consequences, and the intricacies of the relationships surrounding the new technology, however, further "complexified" the problem rather than simplifying it. The employment of the B-29 spawned technological difficulties, awareness of doctrinal failings, Japanese responses, and personal and interservice rivalries that created the need for further systems adaptation. The B-29 alone was not the quick and easy solution promulgated by the Army Air Forces. Only after numerous adaptations at the strategic, operational, and tactical levels and the marriage of the B-29 with another technological tool, the atom bomb, did the U.S. achieve its desired strategic endstate.

Future military strategy and the application of technological tools within that strategy should not be mechanistic, but organic and adaptive. Strategy should consider both the adaptive nature of the enemy system and the uncertainty of strategic inputs in the chaotic environment of war. Future American military strategists pondering the effects of

emerging technology would do well to recall the experience of the B-29 in the Pacific theater during World War II.

This monograph first discusses the theoretical aspects of technology in warfare viewed through the lens of complexity theory. The monograph then details the complexity of the strategic problem facing the United States in the Pacific War against Japan. Focusing on the role of airpower, the monograph presents the strategic bombardment of Japan using B-29s based on the Mariana Islands as a case study in the application of technology to achieve strategic ends, examining both unforeseen difficulties and adaptations necessary to "make it work". The conclusion offers advice and caution for future strategists looking to simplify the complexities of war with linear, mechanical solutions.

Complexity and the Application of Technology in War

"Everything in war is very simple, but the simplest thing is difficult."

Carl von Clausewitz[7]

Uncertainty is an unavoidable aspect of warfare. War, due to its complex and non-linear nature, is an inherently unpredictable venture. The German military theorist Carl von Clausewitz aptly noted the inherent uncertainty of war.[8] For Clausewitz, war was a "true chameleon", ever changing in nature thanks to the elements of chance, friction, and the dynamic relationship between politics and military operations.[9] Only in Clausewitz's absolute war, a theoretical war devoid of context in essence absent of the non-linear relationships of the real world, could the outcome of war be predicted with any certainty.[10] Real war, however, is not so simple. Dynamic interactions within the complex process of war do not lend themselves to this unrealistic theoretical abstraction. "[An] attribute of military action is that it must expect positive reactions, and the process of interaction that results. …the very nature of interaction is bound to make [war] unpredictable."[11]

Greater technological complexity creates greater uncertainty. Innovations in military technology produce quicker, deadlier, and more destructive ways of interacting within the military environment. As a military tool, technology cannot be mechanistically applied within military strategy. The certainty of a machine in an insulated, experimental environment does not guarantee certainty in the chaotic environment of war.[12] Although a technological instrument may theoretically represent a closed system intended to work like clockwork, the environment of war in which it is utilized is an open system subject to

imponderable unforeseen inputs with non-linear effects. This Machiavellian desire to rationalize warfare is a reflection of the faulty mechanistic view inherited from Newton and passed down through modern military theorists.[13]

Airpower planners, given the technical nature of aircraft and munitions, are particularly susceptible to mechanistic approaches to warfare. Airpower strategists, entranced by the technical nature of their tools, tend to view airpower planning as an engineering science, a mere mechanical analysis of weapons and targets.[14] Despite the technical nature of the air instrument, uncertainty is just as important in the application of airpower as with the other military instruments. General Haywood S. Hansell (who would later command the XXI Bomber Command) noted the role of uncertainty in the conception of AWPD-1, the original plan for the conduct of air operations in World War II: "In any measurement system involving probabilities, one never reaches certainty. The more bombs you drop, the greater becomes the likelihood of getting a hit, but you never reach absolute certainty."[15] Misled by scientific paradigms and their doctrinal heritage, airmen frequently overlook the inevitable uncertainties entailed in the complexities of war.[16]

Increased uncertainty demands technological and operational adaptation to achieve desired military objectives. Systems adaptation is the constant revising and rearranging of the building blocks of a system to provide advantage over its environment.[17] Adaptation may involve either a change in the technology itself or a change in the way that the technology is applied. Adaptation is more than just passive defense and survival of the system; it is a proactive measure to meet change head-on.

To be adaptive requires both learning and anticipation. Learning is gaining knowledge from the past; anticipation is essentially knowledge of the future. To effectively adapt, a system must recognize past failures or present opportunities to gain an advantage, and then forecast conditions in the future to anticipate which adaptations will be most effective within this new environment. Successful system adaptation requires knowledge of the past and present combined with cognitive anticipation of the future. Military adaptation requires learning about the operational environment, anticipation of future changes in the operational environment, and then action to effect the necessary adaptation.

What is important to note is that human interaction and input is required. Although conceivable in the future, machines of the past and present do not change themselves to account for environmental conditions. Human innovation and ingenuity are the wellsprings of adaptation. Success in war requires not only being the mechanical application of technological "rules", but also the creative ability to come up with alternative solutions in the face of uncertainty and environmental change. Innovation is the key to success. In war, and especially in the application of technology to war, thinking is required.

Military systems improve their chances of success by increasing their ability to adapt in a dynamically complex environment. Military systems that adapt in the face of dynamic complexity survive and prosper; military systems that fail to adapt, fail to thrive, often suffering the catastrophic consequences of systemic breakdown. Military failure is essentially the failure to cope with complexity.[18] In their historical analysis of military failure, *Military Misfortunes: The Anatomy of Failure in War*, Eliot Cohen and John

Gooch, distinguished strategic analysts, stress that military failures are not individual failures, but systematic failures. Misfortune in war is not usually the failure of individuals to act but rather the failure of the system to adequately function within its environment.[19]

Anticipation is particularly difficult because actions within war are aimed at a similarly thinking and adapting enemy. Like other living systems, the military system must contend with an opposing system that is also adaptive and is, in the creative dance of coevolution, seeking to gain an advantage over its opponent.[20] Successful adaptation requires not only efficacy, but also speed. A military system has to functionally adapt to its dynamic surroundings and adapt quicker than its adversary. Military operations are not aimed at static, unchanging adversaries. They are aimed at dynamic, thinking, similarly adapting systems with hostile intentions.[21] Competition motivates adaptation as competing systems seek to gain advantage over other systems in their environment, in what pre-World War II planners identified as the "inevitable interplay of challenge and response."[22]

This systemic coevolution is clearly evident in the application of technology in warfare. The introduction of new technology often instigates a counter response from the enemy that negates the intended effects of the new technology. The technical devices of war will be opposed whenever possible by other devices specifically designed against them. Often, the very success of new technology spawns those factors that result in its eventual downfall. In a cycle of "action-reaction", enemy forces focus efforts on countermeasures to neutralize whatever devices are most threatening to their existence. Thus, to be continually successful, technology must continue to evolve and adapt to

changing circumstances.[23] Failures of technology in war are frequently the failure to adapt to a dynamic and complex environment.

Military strategy must recognize the complex and dynamic nature of war. Having identified the desired military endstates, strategy should then allow for uncertainty and the necessary adaptation in the application of means to achieve these desired ends. Desired ends are inextricably linked to the means used to pursue them; one cannot be isolated from the other. Clausewitz affirmed the coevolutionary relationship between ends and means:

> But in war, as in life generally, all parts of the whole are interconnected and thus the effects produced, however small their cause, must influence all subsequent military operations and modify their final outcome to some degree, however slight. In the same way, every means must influence even the ultimate purpose.[24]

In prescribing the ways of employing technological means, strategy should recognize the complex and uncertain nature of warfare and the potential impacts of technological means upon planned outcomes.[25] Strategists should plan for adaptation to the inevitable uncertainties of war.

Having laid a theoretical foundation, this paper will now present the experience of the B-29 in the Pacific against Japan as a case study in the application of new military technology. This paper details the complexity of the strategic problem facing the United States in the Pacific War against Japan from late 1944 until the summer of 1945 and examines the role of the B-29 in solving this problem. In examining the employment of the B-29 against Japan, the monograph answers the following questions: Were there uncertainties and unanticipated consequences that accompanied the introduction of this emerging technology? Did these uncertainties further "complexify" the strategic

problem? And finally, what technological, operational, strategic adaptations were required by this increased complexity? To achieve desired ends, adaptive ways must outpace the complex of problems generated by the introduction of new military means. As demonstrated by the successful conclusion of the war against Japan, adaptations outpaced the added complexities introduced by the employment of the B-29 in the Pacific.

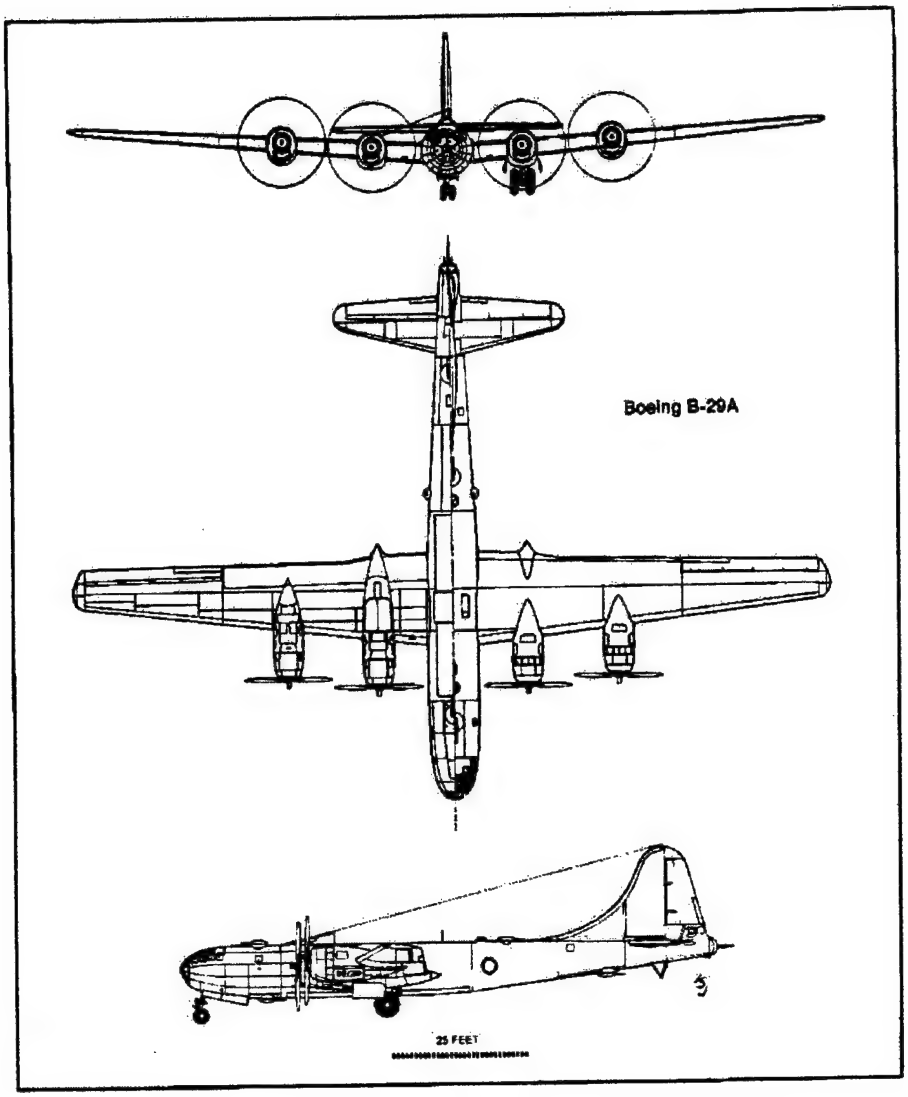

Figure 1: Boeing B-29A Superfortress

Endgame Against Japan: The Strategic Problem

AWPD-1, the first plan for the use of American airpower in World War II drawn up in 1941 at the behest of President Roosevelt and General Marshall, focused primarily on the air campaign against Germany. AWPD-1 provided little detail concerning any future offensive air war in the Pacific against Japan.[26] The United States would contemplate a strategic offensive against Japan only after victory in Europe was assured. Until then, the burden of defense of the Western hemisphere from Japanese aggression fell almost entirely on the U.S. Navy. General Haywood S. Hansell noted that prior to the attack on Pearl Harbor "The American people simply could not believe that Japan would challenge the United States in open warfare."[27] With the attack on Pearl Harbor, the Japanese invalidated Army and Navy prewar planning assumptions in one blow.

As an island nation, wartime Japan depended upon maintaining her newly won "Co-Prosperity Sphere" in the Pacific region for economic support. Hoping to knock out the American threat to her interests in the Pacific by a preemptive blow in 1941, Japan soon found herself fighting a total war to ensure her survival, not a preferred limited war to maintain economic resources. By 1943, Japan was on the defensive throughout the Pacific theater; only in China did the Japanese Army tenuously maintain an upper hand over its adversary. The "characteristically American" war aim of unconditional surrender declared at Casablanca in January 1943 left little room for military or diplomatic maneuver. Only the submission of the Japanese Army and Emperor, either through forceful occupation of the home island of Japan or defeat of the will of decision-makers to resist demands for unconditional surrender, could end the war. To add to the strategic dilemma, planners felt that Americans were not patient enough to withstand a long war

against Japan. Despite the "Europe first" global strategy, theater strategy in the Pacific required continuous pressure against the Japanese to maintain the initiative and win an early surrender.[28]

The geography of the theater added to the difficulties of the strategic problem. The territories occupied by Japan fanned across an enormous geographical area, yet actual landmass accounted for only a small percentage of that area. Ocean dominated the sixty-four million square miles between Hawaii, Australia, the Philippines, and Japan. To defeat the Japanese unconditionally required crossing that ocean, either by hopping across the chain of islands in the Southwest Pacific toward the Philippines and China or crossing the vast expanse of ocean in the Central Pacific directly toward Japan proper. Given these geographic characteristics, initial defense of the Pacific and the eventual counter offensive required the coordinated effort of all three instruments of military power – the Navy, the Army, and the Army Air Corps (renamed the Army Air Forces on 19 January 1942). Victory in the Pacific would necessarily be a joint effort. Despite the organizational parochialism that advocated plans focused upon a single service, each instrument faced limitations to their employment in the Pacific that could only be solved by cooperation with the other services.

The U.S. Army in the Pacific under Douglas MacArthur preferred the island route originating from the Southwest Pacific. The Navy under Chester Nimitz saw the Pacific war as a blue-water naval war that demanded direct action across the broad expanse of the Central Pacific. The Army Air Force, covetous of bases within striking distance of Japan, in a somewhat ironic twist supported the Navy's plan for a more direct approach toward Japan.[29] The actual plan, arrived at in the summer of 1943 by the Combined

Chiefs, was a somewhat diluted compromise between the services, a Twin Axis strategy that would allow both the Army and the Navy to pursue its own plan in contribution to the overall defeat of Japan. Fed by the power of personalities and service proponency, the U.S. would spend tremendous resources fighting this two-pronged strategy in the Pacific. [30]

Strategic airpower proponents saw differences of opinion between the Army and Navy as an opportunity to prove the validity of their argument for autonomy of the air arm. The distances involved suggested that the air component might hold a unique advantage over either the Army or the Navy in the prosecution of the war. Yet given the limitations of aircraft range and endurance, even zealots for independence of the Air Forces were forced to admit the necessity of cooperation with the other services to provide and protect bases for aircraft operating against Japan. The character of air operations in the Pacific was different than in Europe; strategic bombing would only become tenable when territory within range of mainland Japan was in Allied hands. In the minds of Air Force planners, the Army and the Navy would conquer the geography to enable independent air operations; the emerging technology of the Boeing B-29 Superfortress would provide the range and coercion to bring an unconditional end to the war against Japan. As early as October 1940, General Henry "Hap" Arnold foresaw the B-29 as the one weapon that could "exert pressure against Japan without long and costly preliminary operations."[31]

The Doctrinal and Technological Development of the B-29

Prewar United States Army Air Corps doctrine stressed the ability of the air arm to independently provide decisive force through strategic air bombardment. Doctrine for strategic bombardment derived and professed by the Air Corps Tactical School at Maxwell Field in Alabama was built around four assumptions.[32] The first of these assumptions, espoused first by Italian air theorist Gulio Douhet, was that the bomber would always get through. Given the speed, range, and altitude limitations of pursuit aircraft, this assumption was well founded in the 1920's and early 1930's; however, theorists failed to anticipate improved aircraft design that would make the bomber extremely vulnerable without fighter escort and the adaptive development of defensive measures, including radar.[33] Early British and German experience demonstrated the vulnerability of the bomber; Americans, however, ascribed these results not to bombing doctrine, but instead the lack of sufficient defensive armament on the bombers. Well-armed American "Fortresses" and "Superfortresses" could do better.[34] To keep the bombers clear of ground-based air defense systems and low altitude fighters, American planners, in their second assumption, concluded that high altitude bombardment held the best chances for success. The third American doctrinal assumption was that bombers could accurately deliver precision attacks against individually selected targets. Air planners pointed to the existence of "critical nodes" in enemy infrastructure that could be precisely targeted and destroyed, the result being the collapse of enemy systems. The will of the enemy population was not a suitable direct target but would be affected secondarily by destruction of the nation's infrastructure. Finally, to achieve the required precision, American air planners determined that strategic bombardment would be most

effective during daylight hours. With the threat of enemy fighters assumed away, daylight offered the best chance to find and precisely strike discrete targets. From these four basic assumptions, ACTS developed the doctrine of high-altitude, daylight, precision bombardment that would guide the strategic use of American airpower until 1945. The independent nature of strategic bombardment doctrine would fuel the Army Air Corps' informal drive for autonomy throughout the war.[35]

To effect the doctrine of daylight, high altitude, precision bombardment, American airmen needed bombers to fit the bill. However, technological limitations impeded bomber development in the 1920's and early 1930's. Only with developments in metallurgy that allowed the construction of a light, all metal, monoplane and the improved features of closed cockpits, retractable landing gear, and fully cowled engines, did the possibilities of long range bombardment become reality.[36]

Using the rubric of coastal defense as rationalization, advocates from the Air Corps Tactical School pushed for the development of long range bombers at the expense of pursuit aircraft.[37] In the summer of 1932, the Air Corps fielded the Martin B-10, a significant improvement over existing bombers that included enclosed cockpits, a monoplane design with larger wings, a power nose turret, and a remarkable speed of 207 miles per hour.[38] But the real leap in bomber development came with the introduction of the Boeing B-17 in 1935, dubbed by its manufacturer "an aerial battle cruiser, a veritable flying fortress." With its unique silhouette, four big engines, impressive defensive armaments, a range of over 2000 miles, and average speed of 233 miles per hour, the B-17 Flying Fortress became perhaps the most famous airplane in the history of the Air Corps.[39] But even the improved performance characteristics of the B-17, and other

bombers like the Consolidated B-24 Liberator, were inadequate for the operational demands of the Pacific theater. What was needed instead was a *very* long range (VLR) bomber that could exceed 3000 miles in range with a significantly larger payload. This need for VLR bombers became especially important by the end of 1941 with Russia nearing collapse, Britain's demise not out of the realm of possibility, and a broad expanse of ocean standing between U.S. operating bases and the Japanese mainland.[40]

In January 1940, the Army Air Corps issued a design requirement to American aircraft manufacturers for a VLR bomber.[41] The answer to this request was the Boeing B-29 Superfortress and a parallel project, the Convair B-32 Dominator, cut short almost at birth due to technical difficulties and production delays.[42] The B-29 was on the cutting edge of aircraft technology when first flown in 1942.[43] Twice as heavy as the B-17 with a crew of eleven men, the B-29 could carry a 20,000 pound bomb load a distance of over 3000 miles at a speed 30 percent faster than the B-17.[44] The B-29 was the progenitor of both American and Soviet modern bomber technology. But the advanced features of the B-29 taxed the limits of American aircraft industry. It was, in fact, so advanced that designers at Boeing themselves were uncomfortable with the aircraft, feeling that they were going to far forward into the technological unknown.[45] The Air Force's program director, General Kenneth B. Wolfe, called the bomber a "three billion dollar gamble."[46] But given the demands of the strategic environment of World War II, American planners and designers were willing to take the gamble.

The most technologically advanced aspects of the Boeing B-29 were its engines that provided the necessary range and carrying power, the pressurization system that allowed it to operate at high altitudes, the bombing systems that facilitated precision

bombardment, and the automated defensive system that justified the name "Superfortress". The eighteen-cylinder Wright R-3350 engine, the largest engine available at the time of the B-29's development, used two superturbochargers to drive propellers 16.5 feet in diameter at 2200 horsepower.[47] In the 1200-mile flight from Saipan to Tokyo, the giant engines would consume 6000 gallons of gas.[48] The engines facilitated the climb to the operational altitude of 30,000 feet and, combined with the huge Boeing "117" wing, gave the B-29 a maximum range of nearly 6000 miles.

One of the technological demands of the doctrine of high altitude bombing was the need for aircraft pressurization. Pressurization in the B-29 provided a cabin altitude of 8000 feet for the crew while flying at an altitude of 30,000 feet. The B-29 had two pressurized sections fore and aft connected by 40-foot tunnel large enough for men to climb through. This tunnel was a solution to the problem of maintaining pressurization while opening the bomb bay doors. Although not the first combat aircraft to incorporate pressurization (German and British air forces had experimented with pressurized cockpits in combat aircraft), none was as sophisticated or could pressurize such large crew areas.[49]

American strategic bombardment doctrine also required precision delivery of munitions on target. To meet this requirement, the B-29 included the Norden bombsight and the AN/APQ-13 radar. Although primarily intended to aid in navigation, the B-29's radar system could also be used for identification of ground targets, as previously demonstrated by B-17s and B-24s flying over Europe. This technique was especially useful during periods of bad weather when clouds obscured the target, ruling out the use of the sight dependent Norden bombsight. Later B-29s were fitted with a new and more

efficient targeting radar, the AN/APQ-7 Eagle radar, and the AN/APN-4/9 Loran navigation systems.[50]

The remote controlled defensive gunnery system put the B-29 in a class all its own.[51] This defensive system designed by General Electric consisted of ten .50 caliber machine guns and one 20mm cannon mounted in the tail. The four machine gun turrets were computerized, giving control of the gun turrets to more than one gunner. Each gunner had a primary turret but could operate two turrets at the same time if necessary. The central gunner's section had a master gunnery panel where the central fire control gunner could assign turrets to gunners who had the best view of the target. Each gun had a sophisticated gun sighting mechanism that used incandescent light to sight targets. Gyroscopes and the fire control computer allowed the system to lead the target and provide the correct gun elevation to compensate for range to the target.

The combined technological advances of the B-29 made it the weapon of choice for demonstrating the validity of high-altitude, daylight precision strategic bombardment. Army Air Force planners calculated that the mechanical combination of the doctrinal script with the B-29's advanced technology would equate to desired results. Reality in the strategic environment of the Pacific theater proved somewhat more complex and infinitely less predictable.

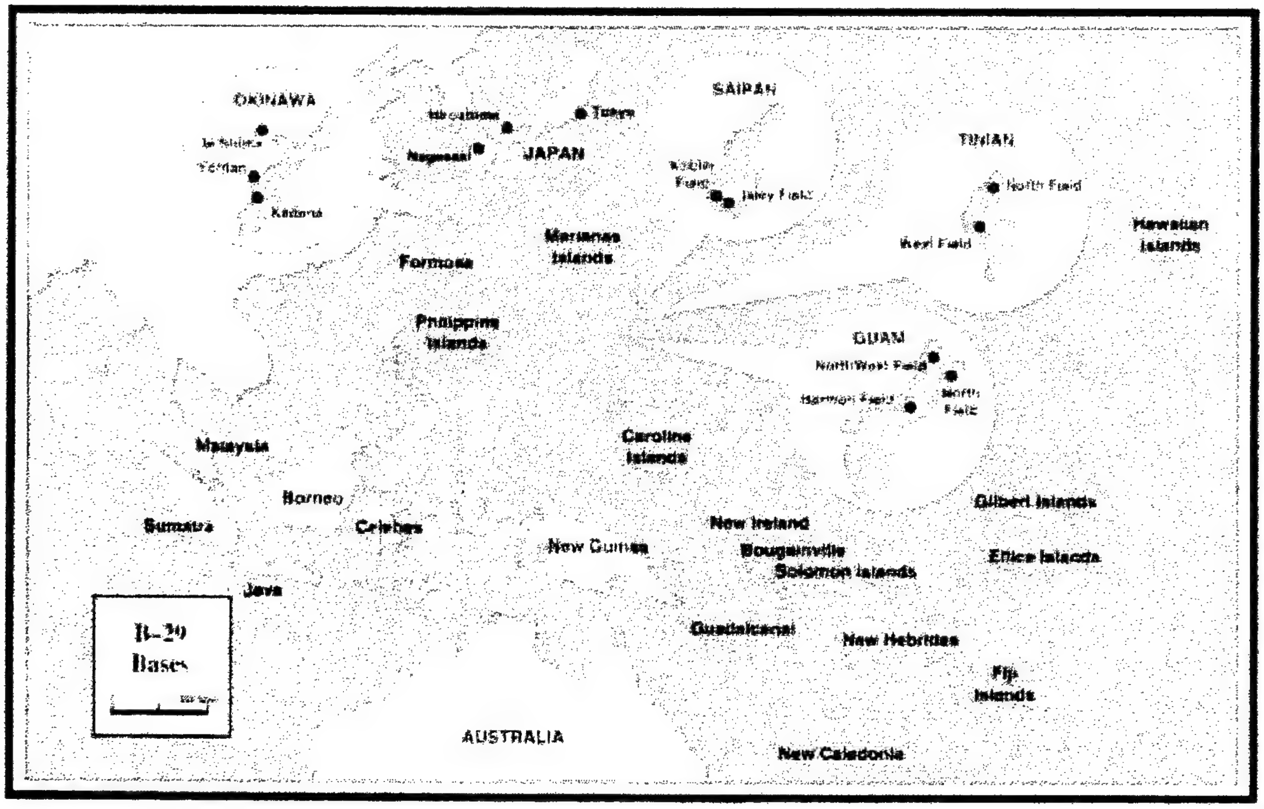

Figure 2: B-29 Bases in the Pacific

Application of A Technological Solution

With the emergence of very long-range bombers, airmen had renewed confidence in the abilities of technology to fulfill the theoretical ends of interwar doctrine. General Hap Arnold would later proclaim, "The combination of technical advances and the state of international relations… gave 'air power' a chance for mushroom growth." [52] Availability of VLR bombers, however, was still a limiting factor. Production schedules suggested to planners in 1941 that the B-29, the B-32, and the B-36 would not be available for several years, and, therefore, the weight of any air offensive early in the war would rest primarily with the B-17 and B-24. Only when the B-29 and B-36 became

available in greater quantities would they be given greater emphasis.[53] The B-29 was originally prioritized to the European theater; AWPD-1 called for twelve groups of B-29's most likely stationed near Cairo for operation from the Mediterranean basin, and another twelve groups operating out of Northern Ireland.[54] Conditions changed, however, and they were deployed first to the Pacific theater.

After losing the backbone of the surface fleet at Pearl Harbor, the U.S. Navy was no longer capable of performing the defensive duties envisioned for it by initial wartime planning.[55] European air planners now rightfully feared that "the bombers consigned to the strategic air war in Europe [to include the B-29] might be reassigned – or diluted in number – to meet emergency demands from the Pacific."[56] AWPD-42 was the first air plan to provide detailed planning for a strategic bombing campaign against Japan.[57] The first call for strategic bombing operations in the Pacific came as a result of the Casablanca Conference of January 1943 as a remedy for the desperate position of the Chinese government and the inability of the Allies to administer help in any other way. In August 1943 the Air War Plans Division prepared a plan for B-29s operating from rear bases in India and forward bases in China against Japanese lines of communication and Japan proper. To conduct this campaign the JCS created an entirely new organization, the 20th Air Force, under the command of the Commanding General, AAF, Henry "Hap" Arnold. At Cairo in late November 1943, the Combined Chiefs of Staff adopted a "grand strategy" statement that included a significant change of wording recommended by Brigadier Gen Haywood S. Hansell, the AAF's chief planner. The change read, "Our studies have taken account of the possibility that invasion of the principal Japanese islands may not be necessary and the defeat of Japan may be accomplished by sea and air

blockade and intensive air bombardment from progressively advanced bases."[58] Airpower was no longer a supporting arm in the Pacific.

The limitations of strategic airpower doctrine were further exposed in operations like the disastrous Schweinfurt raids in late 1943,[59] but perhaps nowhere more clearly than in AAF operations from India and China known as Operation MATTERHORN. The first attacks against Japanese targets by the newly formed XX Bomber Command in China under the 20th Air Force did not occur until June 1944, nearly a year after conception of Operation MATTERHORN. The initial Japanese objectives identified by an AAF Committee on Operational Analysis on 11 November 1943 were: merchant shipping in harbors and at sea, steel production facilities, particularly coke oven plants, urban industrial areas, aircraft plants, ball bearing plants, and the electronics industry of Japan.[60] Due to the frictions of distance, weather, and mechanical bugs and the under-appreciated difficulties of logistically supporting the operation, the impacts of MATTERHORN upon this target set did not live up to the predictions of the airpower theorists.[61] Logistical difficulties made these limited results extremely costly. For every B-29 over a Japanese target, it took seven other B-29s to carry bombs and gas from India to allow the mission to occur.[62] At their peak, XX Bomber Command could manage only two sorties per month per aircraft, with only half of those sorties directed against the main islands of Japan.[63] Initiated in part to meet political exigencies in China, MATTERHORN was nevertheless limited by military realities, realities that proved beyond the adaptive capabilities of both operators and planners.[64] The last MATTERHORN missions occurred in March 1945 as bases for the B-29 shifted to the Central Pacific.

The Mariana Islands in the Central Pacific offered airpower advocates a viable alternative to Operation MATTERHORN. On 12 March 1944, the JCS issued a strategic directive instructing Nimitz to conduct the invasion of the Marianas in Operation FORAGER enabling a new range of airpower possibilities.[65] Operating from Saipan, just 1200 miles from Tokyo, the B-29s could more effectively attack the home islands of Japan than from Chinese bases.[66] Saipan was one of three islands large enough to support air and naval bases; the other two were Tinian, a few miles south of Saipan, and Guam, the southernmost island that had been an American possession before being lost to the Japanese in 1941. With the brutally costly capture of Saipan, Tinian, and Guam in the summer of 1944, at precisely the same time B-29s were just beginning to launch ill-fated raids from bases in China, a window of opportunity opened for the AAF. Engineers followed closely behind the invasion forces to expand and improve the islands' airfields in preparation for B-29 operations.[67] By June 24, even before the fighting had ended, the first B-29 airfield was under construction.[68] The first B-29, flown by the Generals Haywood Hansell and Ken Wolfe, arrived at Saipan on 12 October 1944.

Control of the B-29s in the Marianas fell under the newly created XXI Bomber Command of the 20th Air Force. Haywood Hansell was the first commander of the XXI Bomber Command. Hansell's crews flew their first combat mission on 28 October 1944. To build experience and learn about the operational environment, the first missions from the Marianas were training missions against the island of Truk and relatively low-risk missions against Japanese positions on the island of Iwo Jima. The mission against the home islands, flown for psychological and military reasons against the Nakajima aircraft

plants in Tokyo, took place on 24 November 1944, involving 111 B-29s airborne for over thirteen hours.[69]

Like Operation MATTERHORN, B-29 raids from the Marianas were not without difficulties. The attack against the Nakajima aircraft plants in November 1944 was typical of the first attempts at precision bombardment against Japanese industry from the Marianas. The raid was cancelled five times over a two-week period due to poor weather over the target. Of the 111 B-29s that participated in the eventual attack, seventeen aborted before reaching Japan and six were unable to bomb because of mechanical difficulties. The attacking bombers encountered winds at altitude of 120 knots while overcast cloud layers almost completely obscured the target area. Of the eighty-eight airplanes that bombed the area that surrounded the plant, thirty-five had to do so by radar. In the end, only forty-eight bombs fell in the factory area, damaging one percent of the building, 2.4 percent of the machinery and injuring or killing 132 people in the factory complex. Two B-29s were lost over the target.[70]

When the XXI Bomber Command failed to deliver "the destructive potential inherent in the B-29"[71] due to continuing difficulties, General Arnold removed Hansell on 20 January 1945 and replaced him with General Curtis LeMay.[72] With a burly physique and a hard-nosed reputation, LeMay was arguably well suited for the job.[73] LeMay had established a distinguished record as a bomber commander in Europe. The 37-year old general had become a favorite B-29 troubleshooter for Arnold. Having replaced General Kenneth Wolfe with LeMay as commander of the XX Bomber Command for B-29 operations from China, Arnold now turned to LeMay to reverse the poor performance of operations from the Marianas. As commander of the XXI Bomber Command, LeMay

was a principal player responsible for shaping the operational, strategic, and tactical adaptations required to overcome the uncertainties that emerged from the employment of the B-29 against Japan.

Uncertainty and Unintended Consequences

"A veil of uncertainty is the one unvarying factor in war..."

Erich von Manstein[74]

The B-29 was best known for its technological advances in engines, pressurization, and remotely controlled defensive armament. It was these technological advances that gave the B-29 the capabilities to accomplish the doctrinally designated role of high-altitude, unescorted strategic bombardment. It was, however, precisely these advances that gave both engineers and crewmembers the greatest difficulty. Notably, the B-29 went from design concept to operational missions in five years. This hasty development resulted in numerous "bugs" that required extensive technological adaptation to overcome.

The Wright R-3350 was renowned not only for its power, but also for the high incidence of engine fires.[75] In fact, an inflight fire originating in the engines had caused the loss of one of the two XB-29 prototypes and its entire crew.[76] One-fifth of all B-29 accidents between February 1943 and July 1945 were caused by engine fires. Once a fire started in an engine it was very difficult to put out; the carbon dioxide fire extinguisher system was inefficient and several engine components were made of highly burnable magnesium. Engine fires were the biggest fear of B-29 crews.[77]

The need for pressurization to perform high altitude missions and the doctrinal demands for robust, remotely controlled defensive armaments were directly competing and technologically challenging requirements. Arnold noted that pressurization was "one of the biggest early headaches."[78] Early problems with pressurization forced practice bombing to be carried out from 15,000 feet instead of the prescribed altitude of 30,000 feet.[79] Problems included rapid depressurization in the case of a rupture of the pressurized compartments (a gunner's worst fear since he might be swept from the aircraft should his sighting blister fail) and window frosting at high altitudes. Despite several modifications such as cockpit fans, gas heaters, and flexible ducts, these problems would persist throughout the war.[80]

The remotely controlled defensive systems were extremely heavy and used non-retracting gun turrets that increased drag and correspondingly decreased speed, range and endurance of the aircraft. One adaptation required by the non-retractable turrets was the addition of a tailskid to keep pilots from grinding off the aft lower turret when making high-angle takeoffs.[81] Airmen at Eglin Air Proving Ground complained that the remotely controlled system was difficult to maintain, vulnerable, and inherently inaccurate. The final report of the Eglin staff concluded, "the defensive armament of the B-29 airplane… is not suitable for a series of unescorted combat operations in theaters where the airplane will be subjected to more than brief, desultory fighter attacks."[82] Despite their vulnerability, inaccuracy, and aircrew preference for locally controlled gun turrets, the General Electric remotely-controlled defensive system was selected for the B-29 because it made the problem of pressurization easier for Boeing designers.[83] Concerns about the inadequacies of the defensive system eventually drove decision makers toward

night missions when few Japanese fighters could effectively operate instead of daylight raids where precision bombing could be more effective.[84]

These robust defensive systems had another important unintended consequence. Flying in relatively tight formations, the B-29's were highly susceptible to incidents of friendly fire. This vulnerability encouraged the removal (at least for a time) of defensive armaments and the change in tactics from formation bombing to single aircraft flying sequentially over the target.[85]

Although frequently intended to be labor saving, new systems often demand more training time and manpower to physically and intellectually process the added technological complexity. The B-29 serves as a case in point. The B-29 was the first operationally employed aircraft requiring the crew position of flight engineer. Facing rearward behind the pilot, the flight engineer on the B-29 was responsible for monitoring and regulating the aircraft's systems. Pilot's were initially reluctant to accept this additional crew position, since it meant that many of the controls would be out of their sight and reach. The position was also difficult to fill since only previously trained officer mechanics were initially accepted into the flight engineer school. Later, as demand grew, the AAF accepted enlisted mechanics. About half of the flight engineers during combat operations in this essential crew position were non-commissioned officers. In an act of desperation to cover unfilled manning requirements, even pilots were recruited for the position of flight engineer. The need for the crew position of flight engineer, vital for successfully completing long-range missions in a technologically complex aircraft, created additional manpower and training requirements.[86]

The technological complexity of the B-29 led to increased manning and training requirements for other crew positions as well. Its design was so radically new that it required exclusively designed courses for each of its components. Radar operators, for example, had no experience with advanced radar systems. Even after July 1944 when radar equipment was plentiful enough to begin training, there were not enough qualified instructors to carry it out. Furthermore, few of the operators trusted the utility of the radar and the plains of Kansas were ill suited to demonstrate its value.[87] Pilot training was complicated early in the program by the lack of airframes. Aircrews were initially forced to use other aircraft for training, with the first crews training in the twin-engine Martin B-26.[88] Despite valiant efforts, the first B-29 crews operating out of the Marianas averaged less than 100 hours of B-29 flying time and less than 12 hours flying in high altitude formations.[89]

Unknowns and unanticipated phenomena in the operating environment were also a source of Clausewizean friction in B-29 operations. Hansell described the weather over Japan "our most implacable and inscrutable enemy."[90] Weather was so poor, especially during the winter, that there were sometimes only three or four good bombing days a month. Obtaining accurate weather forecasts for the Japanese mainland presented a major challenge. For various reasons, weather analysis and prediction in the Pacific was not as good as in the European theater. The importance of weather forecasting was most critical during the first months of B-29 operations with only one runway in operation on Saipan; without a recovery field, a weather divert or a single crashed B-29 on Isley field might spell disaster for those still airborne.

Even more important operationally, B-29 planners and strategists advocating high altitude precision bombing failed to account for the effects of the jet stream in the Pacific on bombing accuracy and aircraft performance.[91] Crews operating at 25,000 feet and above over Japan often found the river of air flowing west to east at speeds over 200 miles per hour. Flying downwind caused groundspeeds exceeding 450 knots, far greater than optimum for accurate precision bombing either visually or by radar. Flying against the jet stream reduced the range of the bombers and left them vulnerable for longer periods of time to enemy air defense. On one mission flown upwind to increase bombing accuracy, aircrews even reported flying backward along the ground, as wind speed exceeded their true airspeed.[92] In the absence of accurate forecasts, the only recourse was to fly at lower altitudes where the jet stream was not as strong.

Beyond the uncertainties of employment, the B-29 introduced greater complexity by presenting unintended consequences for both friendly and enemy systems. One unintended consequence on the friendly military system was further strain on the already convoluted command relationships in the Pacific. The B-29s were placed under direct control of the Air Force Commander in Chief, Henry "Hap" Arnold in Washington.[93] Both General Claire Chennault and General Joseph Stilwell in China continually, although unsuccessfully, demanded operational control of resources dedicated to the B-29 for Operation MATTERHORN, especially after the renewed Japanese *Ishigo* offensive in China in 1944. General Douglas MacArthur, through his air proponent General George Kenney, advocated using the B-29s operationally in the southwest Pacific from bases in northern Australia in support of his island-hopping thrust toward the Philippines.[94] The Navy, perhaps rightly so, feared subordination of their central

Pacific thrust toward Formosa to the strategic bombardment of Japan.[95] One member of Admiral Ernest King's staff noted in 1945, "The interests of the AAF and the Navy clash seriously in the Central Pacific campaign. The danger is obvious of our amphibious campaign being turned into one that is auxiliary support to permit the AAF to get into position to end the war."[96] Dual-hatted as Commanding General, Army Air Forces and Commander of the 20th Air Force, Arnold did not answer to Pacific theater or area commanders, but instead was coequal with the other joint chiefs, responsible in essence only to Marshall and Roosevelt.[97] Had the Navy followed Arnold's lead by placing the10th Fleet directly under Admiral Ernest King, effective unified action in the Pacific between the services might have been well nigh impossible. Command arrangements, in effect, prioritized the B-29 strategic campaign against Japan over all other efforts in the Pacific theater. In the last month of the war, after the artificial area boundaries between MacArthur and Nimitz had become obsolete, Pacific command was equally divided between the Army under MacArthur, the Navy under Nimitz, and the U.S. Strategic Air Force under General Carl Spaatz. Although still technically owned by the Army, the strategic bombardment force was in a position of near equality with the Army and Navy.[98] The introduction of the B-29 enlivened tension between the services and added complexity to the command structure in the Pacific.

The employment of the B-29s on the Marianas, in a dance of coevolution, also affected Japanese military developments. The Japanese understood the dangers of American B-29s operating from the Marianas. Lt Gen Yoshitsugu Saito, the Japanese defender of Saipan, wrote, "...the fate of the Empire will be decided in this one action."[99] Stiff Japanese resistance in the Marianas and later on Iwo Jima was due in part to this

realization. The construction of Isley airfield on Saipan triggered increased Japanese reconnaissance sorties and aircraft attacks staged through the island of Iwo Jima. Although kept under control by the combination of anti-aircraft artillery and Northrup P-61 Black Widow fighters, the attacks did cause some damage. On 27 November 1944, four B-29s were destroyed and 28 others damaged by a Japanese attack. Altogether, Japanese raiders destroyed eleven B-29s, heavily damaged eight, and less seriously damaged 35 others, killing 45 Americans and wounding 200 others at a cost of 37 Japanese aircraft.[100] In its turn, this Japanese evolution to the employment of B-29s from the Marianas would shape the evolution of American actions.

Technological and Operational Adaptation

"Improvisation is the natural order of warfare. The perfect formulas will continue to be found only on charts."

SLA Marshall[101]

Effective and timely adaptation requires learning about the operating environment. Learning about the operational environment for the employment of airpower was the mission of the Air Intelligence Services. First formed in 1940 by Haywood Hansell and Tom White at the request of General Arnold, the Strategic Air Intelligence Section (SAIS) consisted of a system of "Assistant Military Attaches for Air" at U.S. Embassies around the world and an analysis branch at the Pentagon. Their focus included the composition of foreign air forces, the infrastructure (airports and air bases) to support those forces, and also the economic-social-industrial analysis of major foreign powers.[102] Although relatively successful at collecting information about Germany and Italy, the

SAIS was not able to gather much detailed information on Japan given the "curtain of secrecy" that surrounded Japan. Hansell claims that there were not even any recent maps available to air planners.[103] The Army Air Force in the Pacific would learn best through its own experience under the inevitable stress of war.[104]

Surprisingly, the AAF did not take advantage of one of its best sources of operational learning, wartime experience from the European bombing campaign. Although the AAF in the Pacific would employ methods that would come to closely resemble the night fire raids of the RAF in Europe, there is no evidence of shared learning between the two. Intended for use in the Pacific War, the United States Strategic Bombing Survey arrived too late to influence it conduct.[105] Stumbling through to a suitable solution, the AAF in the Pacific neglected sources of learning that might have identified many uncertainties and aided successful adaptation. The strategic air war in the Pacific, on its own, evolved toward the British concept of bombing used in Europe.

Thus, the AAF adapted operationally to the uncertainties initially posed by the B-29 in the Pacific by switching from high-altitude, daylight, precision bombardment raids against critical industrial nodes to low-altitude, night, incendiary attacks against Japanese cities. The turning point came in March 1945, when the commander of the XXI bomber command, General Curtis E. LeMay, switched exclusively to low altitude attacks intended to burn out major Japanese cities.[106] The change to incendiary attacks was in part the result of poor performance during conventional high explosive missions against precision targets. Despite the promises of accuracy from the new technology, the results of radar bombing with the B-29's new AN/APQ-13 radar bombsights were disappointing. The new tactic was not an act of desperation, but a well-considered adaptation first

suggested by air strategists before the war. In his 1937 study "Japan as an Objective for Air Attack," Captain Thomas D. White of the Air Corps Tactical School noted: "Large sections of Japanese cities are built of flimsy and highly inflammable materials. The earthquake disaster of 1924 bears witness to the fearful destruction that may be inflicted by incendiary bombs."[107] Even Admiral Isoruku Yamamoto had pointed out this vulnerability as early as 1939: "Cities made of wood and paper would burn easily. The army talks big, but if war comes and there were large-scale air raids, there is no telling what would happen."[108] Japanese fire-fighting equipment was primitive and inadequate for the disaster that was about to befall Japanese cities. The nature of targets in Japan was different than those in Germany; Japanese industry, more widely dispersed within Japanese cities, was less vulnerable to precision attack. The cities themselves, however, were extremely vulnerable to fire bombing.[109]

Prior to 1945, strategists in Washington, including Arnold, had pressed for incendiary attacks, but both Hansell and LeMay opposed incendiary attacks in favor of doctrinally conventional precision bombardment.[110] Hansell's preference for precision bombardment in the end would, at least in part, cost him his job.[111] Motivations to move away from precision attacks included the cost of unescorted daylight missions, the vulnerability of Japanese cities and the failures of pinpoint bombing against Japanese industry.[112] Not until December 1944 did LeMay, then still commanding the 20th Bomber command in China, launch the first incendiary raid against the Chinese city of Hankow.[113] Even after the Hankow raid, B-29's continued using high-altitude, conventional attacks since incendiaries had proven relatively difficult to deliver from the altitude of 30,000 feet used during testing and evaluation. These difficulties in accurately

dropping incendiaries from high altitudes led to a switch to lower altitude. Flying at lower altitudes also avoided the unpredictable navigation and bombing effects of the jet stream and reduced engine wear from the high power climb to altitude, improving engine reliability. The introduction of a more explosive incendiary, the M69, by the Army's Chemical Warfare Service made incendiary attacks potentially even more lethal.[114] An encouraging test incendiary raid against Tokyo on 25 February 1945 resulted in the complete burning out of about a one square mile area of the city.[115] One massive raid in March burned out some 16 square miles of Tokyo or about 18 percent of the city's industrial area and 63 percent of the commercial area.[116] The only major limiting factor to incendiary operations was the supply of napalm bombs; these weapons were in such demand toward the end of the war that supply crews would drive them directly from supply ships to bombers awaiting on the airfields.[117] Incendiary raids from low altitude essentially overwhelmed Japan's ability to adapt defensively.

To facilitate greater bomb loads, LeMay had B-29s stripped of guns and ammunition. The B-29 normally carried 1.5 tons of armament that could now be carried in bombs.[118] This adaptation was spurred not only by the desire for more destructive effects on Japanese targets, but also by the lack of adequate Japanese night fighters to oppose the B-29 incendiary raids. Although efficient tactically, the removal of defensive systems had less predictable effects on crew morale. Despite the lack of opposition, the guns were once again put back on at the insistence of crew unwilling to fly defenseless.[119] One other adaptation to defensive systems from combat experience was the removal of the 20mm tail gun and the addition of two more .50 caliber machine guns to the forward upper turret, since Japanese fighters preferred head on attacks against the fast bombers.[120]

A simple mechanical cam follower was also included on the forward upper turret to prevent gunners from shooting off parts of their own airplane – a worst case incident of fratricide.[121]

One strategic adaptation dictated by the employment of the B-29 was the capture of Iwo Jima in March 1945. Taking Iwo Jima provided several benefits to B-29 operations: occupation eliminated Japanese radar outposts on the island, removed the threat of Japanese fighters operating from Iwo Jima against B-29 bases in the Marianas, allowed direct B-29 overflight of Iwo Jima shortening the distance to Japanese targets and facilitating navigation, provided critically need emergency recovery airfields for crippled B-29's, and could even serve as a forward staging base for deeper strikes against Japan.[122] Although the Marines did not declare the island secured until 26 March, the first B-29 to make an emergency landing on the return trip from Japan occurred three weeks earlier on 4 March. This strategic adaptation cost the precious lives some 5000 U.S. Marines, but potentially saved as many as 22,000 crewmen from the 2251 crippled B-29s that landed at Iwo Jima who might otherwise have had to ditch and been lost at sea.[123]

Iwo Jima also could serve as a base for escort fighters to accompany the B-29's on their raids into Japan. This was also dictated by the deficiencies in the B-29's defensive systems. Ironically, by the time sufficient numbers of long-range escorts were available and a base at Iwo Jima was ready to accept them, the escorts were no longer needed given the virtual absence of a threat from the Japanese Air Force. Instead, these fighters proved more useful to the strategic air war by serving in the ground attack role against various Japanese targets.[124] Although changes in the tactical situation lessened the importance of

Iwo Jima toward the end of the war, its value to the strategic air campaign can not be underestimated.[125]

Another strategic and operational adaptation of the B-29 was its use as a mine-laying instrument to blockade Japanese sea lines of communication.[126] The first mining operations occurred as early as August 1944 against Japanese lines of communication in the Southwest Pacific. The B-29s of the 20th Air Force did not launch a sustained mining campaign however until January 1945. Although the initial Army Air Force response to the Navy sponsored mining plan was initially negative, the aerial delivery of mines proved to be an effective use of the B-29 when weather prohibited bombing and was eventually favorably received by LeMay. In the 20th Air Force campaign aptly code-named Operation STARVATION, B-29s sowed some 12000 naval mines.[127] Submarine attacks, aided by the aerial dropping of mines, were arguably economically decisive against Japan. By 1945, Japan had lost 9 million of its 10 million tons of merchant shipping.[128] According to Japanese records, the aerial mining campaign accounted for sixty-three percent of all Japanese merchant shipping losses during the final half-year of the war.[129]

In the closing days of the war, XXI Bomber Command came up with yet another operational use for the B-29 to further the prosecution of the war. By dropping leaflets on Japanese cities, B-29s warned the civilian populace of upcoming attacks to disrupt production, lowered morale, and encouraged civilians to replace the current leadership. Beginning on 27 July, the leaflet drops were followed by shortwave broadcasts.[130] All total, the B-29s scattered some 4.5 million leaflets over Japanese cities.[131]

To overcome the uncertainties of weather, American crews relied almost exclusively upon B-29 reconnaissance flights nightly toward Japan. Whereas in Europe, aircrews had depended a great deal on Ultra intelligence reports for weather information, both Hansell and LeMay had assumed that this type of information was unavailable for the Pacific theater. Unfortunately, as Hansell and others would find out thirty years after the war, Allied intelligence agents in Australia were receiving Japanese weather reports throughout the war but had not passed this information along.[132] Put in the context of complexity theory, lack of shared learning about the operational environment prohibited effective adaptation.

Adaptation included not only strategic and operational adaptations, but also other technical, mechanical, and procedural adaptations necessitated by simultaneous of production, training and employment. To improve mechanical reliability and overcome the uncertainty involved with the complex technology of the B-29, LeMay changed from "crew chief" maintenance to "production line" maintenance. Instead of being responsible for maintenance of the entire aircraft and all of its systems, individual specialist were now responsible for separate components on the B-29. This system eased the problems created by a shortage of maintenance personnel and the lack of adequate maintenance training.[133] The result was more aircraft in commission, fewer aborts, and a greater percentage of aircraft bombing their primary targets. A secondary effect with negative implications was the increase of crew stress and flying fatigue that severely affect flight crew morale thanks to the improved aircraft reliability rates.[134]

Avoiding engine fires involved a combination of mechanical fixes and changes in crew technique. Later models of the B-29 included shortened cowl flaps and improved

lubrication to reduce the chances of engine fire. New cowl flaps, ducted baffles to better circulate air, and oil crossover tubes to better circulate oil were installed at the Oklahoma City Air Depot beginning in September 1944 and sent in kits to combat forces in late 1944.[135] To minimize overheating of the huge engines during the ground takeoff run., crews ignored technical order takeoff speeds and instead would use the entire length of runway to achieve maximum ground speed to increase cooling air flow over the engines before becoming airborne.[136] The result of these adaptations was that engine temperatures were kept below desired limits and the life of the engines began to increase.[137]

Another required adaptation was the development of the necessary logistical structure to support B-29 operations from the Marianas. This was primarily the result of the efforts of Lt. General Millard F. Harmon. Harmon was appointed Deputy Commander of the 20th Air Force and Commander of the AAF Pacific Operations Area upon its activation on 1 August 1944 to centralize logistical and administrative responsibility for all AAF forces in the Central Pacific.[138] Harmon's direct personal effort, in particular, was responsible for bringing up to speed the runway construction effort on the Marianas after it had fallen behind original planning schedules. Despite the 8000 miles back to the air logistics center in Sacramento, California and direct competition for resources with the Navy, supply problems never affected operations as seriously as they had in the China-Burma-India theater.[139]

Successful adaptation required the energetic intervention of key individuals throughout the process, including not only Curtis LeMay, but also Hap Arnold. When delays pushed the initial operations date back from the summer of 1943 to the spring of

1944, Arnold made an inspection trip to the Boeing production facility in Wichita and the B-29 training base at Salina, Kansas.

> "I was appalled at what I found there. There were shortages in all kinds and classes of equipment. The engines were not fitted with the latest gadgets, the planes were not ready to go. It would be impossible for them to be anywhere near China by the 15th of April unless some drastic measures were taken."[140]

Arnold's "drastic measures" included an intensive six-week modification and upgrade effort to the program that became known as the "Battle of Kansas." In June 1945, it would take a personal visit by Arnold to the island of Guam to overcome command and logistical disputes with the Navy.[141] One unintended consequence of Arnold's energetic interventions was a series of heart attacks in 1944 and 1945 that ruined Arnold's health.[142] Before his removal from command, Hayward Hansell also took several steps to improve B-29 aircrew training. These actions included providing additional training in theater for combat crews and the establishment of a school for lead crews.[143] Adaptation was not the result of chance and circumstance, but of human vision and the will and energy to follow through.

Conclusion

"The war was lost when the Marianas were taken away from Japan and when we heard the B-29's were coming out.... We had nothing in Japan that we could use against such a weapon. From the point of view of the Home Defense Command, we felt that the war was lost and we said so. If the B-29's could come over Japan, there was nothing that could be done."

Prince Higashikuni
Commander in Chief, Home Defense HQ[144]

Given the costs of modern military technology, there is a duty for military strategists to study its application and use it wisely. This is especially true for airpower strategists. Airpower and technology are integrally and synergistically related. An understanding of airpower and its place in national strategy requires an understanding of the efficient application of technology in warfare. As demonstrated by the American experience with the Boeing B-29 Superfortress, efficient application of military technology requires an appreciation for the inevitably of uncertainty in war and the need for adaptation to these inevitable uncertainties. Military planners should not avoid new technologies because of the increased complexity that they represent.[145] Instead, they should acknowledge the demands this complexity encompasses and allow for flexibility and adaptation in the use of military technology. Technology and military strategy should be fully integrated to "...enable commanders to conduct the kind of campaigns and military operations that stand the best chance of achieving the nation's political and military objectives."[146]

One finding from the study of B-29 operations in the Pacific through the lens of complexity theory is the failure of the Japanese to adapt. American success was not only a factor of offensive adaptation, but also the lack of Japanese defensive adaptation.

Similar to the American neglect of British experience but to a greater degree, the Japanese failed to learn from German successes against the European air campaign.[147] Unlike the Germans, the Japanese did not disperse their industries until it was too late and did not organize a credible air defense. The Japanese did not acquire German radar technology, but instead used British and American radars captured during the first years of the Pacific war.[148] What little adaptation the Japanese did show, such as concentrating fighters and flak around probable targets and creating "aerial Kamikazes" by ramming American bombers, was uncoordinated and not widely adopted.[149] In an evolutionary response to the threat of aerial and naval Kamikazes, LeMay, at the behest of the Navy, did focus efforts against Japanese airfields on Kyushu in support of the campaign against Okinawa.[150] Limited materially, Japanese responses to the mining campaign were also woefully inadequate.[151] The negative lesson from the Japanese may be as important as the positive lesson from the American experience.

The Japanese theater presented uncertainties and unintended consequences that required adaptations from each of the services. The Army shaped itself in an image of the Marines, learning the demands of island warfare. The Navy evolved from the battleship to the aircraft carrier and from Mahanian decisive engagements to submarine warfare aimed at strangling the enemy into submission. The Air Force and the B-29 were not alone in the need for adaptation of strategy, operational methods, and tactical devices in the Pacific theater. War is full of uncertainty that requires adaptation to overcome. The uncertainties presented by the introduction of the B-29 to the Pacific theater included mechanical malfunctions, doctrinal shortcomings, and unintended consequences within

the military environment in the Pacific theater. These uncertainties required extensive technical, operational, and strategic adaptations to overcome.

Despite the difficulties it presented, the B-29 proved to be a successful instrument for achieving strategic and operational goals against Japan in the Pacific. The B-29 was successful in ways that planners and aircraft designers had not anticipated. With LeMay's operational adaptations, the technology-based doctrine of precision daylight bombardment fell victim to the necessity of military expediency. The technological developments that drove the initial employment of the B-29 by the AAF proved the least important in the successful conduct of strategic bombing against Japan. Touting the technological advances of pressurization and remotely controlled defensive armaments, the B-29 succeeded not as a high-altitude, precision bomber but as a low-altitude, area bomber using incendiaries against highly vulnerable Japanese cities. Instead, range, payload, and adaptability became its greatest assets.

Taking into account the costs of both the unforeseen difficulties and the necessary adaptations, the B-29 was a costly, high maintenance tool for achieving wartime objectives. Given the probable cost of other alternatives, however, the B-29 was almost certainly well worth it. In sheer killing power alone, the Strategic Bombing Survey determined that the B-29s caused 330,000 fatalities and 806,000 injuries, far exceeding Japan's 780,000 combat casualties for the entire war.[152] Japan's economy was twice destroyed. B-29s participated in both arms of the economic strangulation of Japan, both by destruction of industries from the air and the mine-laying campaign to cut off imports by sea. With or without the technology of the atom bomb, the technology of the B-29

was a war winner. The experience offers valuable insight into the successful application of emerging technology in war.

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[1] In a complex system, "...a great many independent agents are interacting with each other in a great many ways." For an accessible account of complex, adaptive systems, see M. Mitchell Waldrop, Complexity: The Emerging Science at the Edge of Order and Chaos (New York: Simon and Schuster, 1992). The definition of a complex system is taken from Waldrop, p. 11. For the military applications of complexity theory see David S. Alberts and Thomas J. Czerwinski, eds. Complexity, Global Politics, and National Security (Washington: National Defense University, 1997). For a sense of the difficulties of applying the scientific theories of complexity and chaos, see especially Waldrop, pp. 9-13.

[2] There are two different types of complexity. The first is detail complexity, where numerous parts or agents make up the whole. The second is dynamic complexity, systems with numerous interactions among agents, where cause and effect are subtle and the effects over time of various interactions and inputs are not obvious. Full awareness of systems complexity requires not only a recognition of the vast number of parts, but also an understanding of the elaborate relationships between the individual parts that produce the characteristics of the system as a whole. Open systems, subject to inputs and interactions from outside systems and the surrounding environment, present yet another level of dynamic complexity. See Peter M. Senge, The Fifth Discipline: The Art and Practice of the Learning Organization (New York: Currency Doubleday, 1990), pp. 71-72. For an explanation of open systems, see Ludwig von Bertalanffy, General System Theory (New York: George Braziller, 1968) pp. 39-41 and 139-154

[3] For a system to be linear, it must meet two conditions. The first is *proportionality*, indicating that changes in system output are proportional to changes in system input. The second is *additivity*, where the whole is equal to the sum of the parts. Non-linear systems, such as war, are those that disobey proportionality or additivity. Alan D. Beyerchen, "Clausewitz, Nonlinearity and the Unpredictability of War," in Tom Czerwinski, ed., Coping with the Bounds: Speculations on Nonlinearity in Military Affairs (Washington, D.C.: National Defense University, 1998), pp. 161-215. The description of mathematically linearity is taken from pp. 165-166.

[4] For an explanation of "the butterfly effect", see is James Gleick, Chaos: Making a New Science (New York: Viking, 1987), pp. 20-23

[5] For a discussion on the definitions of strategy, see Edward N.Luttwak, Strategy: The Logic of War and Peace (Cambridge, MA: Harvard University Press, 1987), pp. 239-241. Strategy, for the purposes of this paper, refers to theater military strategy, most closely following Irving B. Holley's definition of strategy as "the art of military command exercised to meet the enemy in combat under advantageous conditions." Irving B. Holley, "Technology and Strategy: A Historical Review," in Franklin D. Margiottaand Ralph Sanders, eds., Technology, Strategy and National Security (Washington, D.C.: National Defense University Press, 1985), p. 17.

[6] Arden Bucholz defines military technology as "the systematic application of scientific knowledge to the practical task of war planning." Arden Bucholz, Moltke, Schlieffen, and Prussian War Planning (Providence, RI: Berg Publishers, Inc., 1993), p. 168. John Kenneth Gailbraith defined technology as the systematic use of organized knowledge applied to practical skills. Gailbraith emphasized that the introduction of technology to organizations leads to increased procedural rigidity. The use of specialized technology leads to division and subdivision of labor to align tasks with scientific and engineering knowledge. As technology becomes more discrete, procedures become more inflexible and harder to change. More complex procedures and organizational structures lead to greater functional inflexibility. John Kenneth Gailbraith, The New Industrial State (London: 1972), chapter 2.

[7] Carl von Clausewitz, On War, Peter Paret and Michael Howard, eds. (Princeton: Princeton University Press, 1984), p. 119.

[8] Beyerchen writes that Clausewitz understood that "seeking exact analytical solutions does not fit the non-linear reality of the problems posed by war, and hence our ability to predict the course and outcome of any given conflict is severely limited." Beyerchen, "Clausewitz, Nonlinearity and the Unpredictability of War," pp. 163-164.

[9] Clausewitz clearly identified the nonlinear nature of war and the complex nature of interactions in war. "But in war, as in life generally, all parts of the whole are interconnected and thus the effects produced,

however small their cause, must influence all subsequent military operations and modify their final outcome to some degree, however slight. In the same way, every means must influence even the ultimate purpose." Clausewitz, p.158.

[10] Beyerchen, "Clausewitz, Nonlinearity and the Unpredictability of War," p. 172.

[11] Clausewitz, p. 139.

[12] "In war…all action is aimed at probable rather than at certain success." Ibid., p. 167.

[13] Since the Enlightenment of the 18th century, Western theory has centered on scientific interpretations of the world. Specifically, Newtonian physics has shaped Western understanding of cause and effect. Taken from the world of physical mechanics and applied across the academic and social disciplines from psychology to government, Newtonian models speak mechanistically of "the clockwork universe", describing efficient social systems as "well-oiled machines". Military theory is not exempt. Thanks in large part to the nineteenth century fathers of modern military thought, Carl von Clausewitz and Antoine de Jomini, modern military theory also rests upon physical concepts borrowed from the Newtonian paradigm: friction, centers of gravity, geometric points and lines, and mechanical synchronization of military operations. The Newtonian paradigm dominates modern military theory. John F. Schmitt, "Command and (Out of) Control: The Military Implications of Complexity Theory," Marine Corps Gazette (September 1998), pp. 55-56.

[14] Barry Watts, The Foundation of U.S. Air Doctrine: The Problem of Friction in War (Maxwell Air Force Base, AL: Air University Press, 1984), pp. 22-23.

[15] Haywood S. Hansell, Jr., The Air Plan That Defeated Hitler (Atlanta, GA: Longino & Porter, Inc., 1972), p. 10.

[16] Barry Watts points out the tendency of American airmen to ignore "… the complex amalgam that Clausewitz called 'friction in war'." See Watts, pp. 43-58.

[17] Waldrop, p. 146.

[18] "…the *sine qua non* of a successful military organization is the capacity to adapt to changing conditions better than the enemy, the implication being that sound theory can do much to facilitate such adaptation". Watts, p. 47.

[19] Eliot A. Cohen and John Gooch, Military Misfortunes: The Anatomy of Failure in War (New York: The Free Press, 1990), pp. 21-23. See also pp. 161-163. Cohen and Gooch identify three reasons for military failure: failure to learn, failure to anticipate, and failure to adapt. Of these three elements, they identify adaptation as the most important capability for a military organization. "Indeed, the ability to adapt is probably most useful to any military organization and most characteristic of successful ones, for with it, it is possible to overcome both learning and predictive failures." Cohen and Gooch, p. 94.

[20] Waldrop, pp. 259-260. The ancient Chinese military theorist Sun Tzu recognized the significance of coevolution in military systems when he wrote of the importance of shaping oneself in accordance with the enemy. "Water configures its flow in accord with the terrain; the army controls its victory in accord with the enemy… One who is able to change and transform in accord with the enemy and wrest victory is termed spiritual." Sun Tzu, The Art of War, Ralph D. Sawyer, trans. (Boulder: Westview Press, 1994), p. 193.

[21] "War is always the collision of two living forces". Clausewitz, p. 77. In declaring war as neither science or art, Clausewitz writes, "The essential difference is that war is not an exercise of the will directed at inanimate matter, as is the case with the mechanical arts, or at matter which is animate but passive and yielding, as is the case with the human mind and emotions in the fine arts. In war, the will is directed at an animate object that reacts." Ibid., p. 149.

[22] Hansell, The Air Plan That Defeated Hitler, p. 49. "…a highly resourceful enemy such as the Germans found it possible to design effective countermoves. Key areas, for example could be skillfully defended, dummy factories could be built, camouflage and smoke screens used, air to air defenses strengthened, repair methods improved and refined, and very vital points hardened by putting them underground. During the planning phase, we sensed this inevitable interplay of challenge and response and, as later events proved, we somewhat overestimate our challenge and underestimated their response."

[23] Luttwak, pp. 27-28.

[24] Clausewitz, p. 158.

[25] "The original political objectives can greatly alter during the course of the war and may finally change entirely since they are influenced by events and their probable consequences." Ibid., p. 92.

[26] The strategic priority of the plan was the war against Germany. The Air Force would support a strategic defense in the Pacific Theater and only after the defeat of Germany would there be emphasis on an offensive strategic air war in the Pacific. Hansell, The Air Plan That Defeated Hitler, pp. 42-46. For a critique of the mechanistic nature of AWPD-1, see Watts, pp. 17-22.
[27] Hansell, The Air Plan That Defeated Hitler, p. 34.
[28] Russell F. Weigley, The American Way of War: A History of United States Military Strategy and Policy (New York: MacMillan Publishing Co., Inc., 1973), p. 281.
[29] Ronald H. Spector, Eagle Against the Sun: The American War with Japan (New York: Vintage Books, 1985),, p. 279.
[30] For an examination of the reasons behind the two separate campaigns and an analysis of their consequences, see J.C. Wylie, Jr., "Reflections on the War in the Pacific," United States Naval Institute Proceedings 78, no 4 (April 1952), pp. 357-361.
[31] Richard P. Hallion, "Prelude to Armageddon," Air Power History 42, no. 3 (Fall 1995), p. 42.
[32] For the evolution of airpower doctrine in the United States before WWII and the controversy between bomber and fighter advocates, see Thomas H. Greer, The Development of Air Doctrine in the Army Air Arm, 1917-1941, USAF Historical Study 89 (Maxwell AFB, AL: USAF Historical Division, Air University, 1955). For a succinct account, see James Lea Cate, :Development of Air Doctrine, 1917-1941," Air University Quarterly Review 1, no. 3 (Winter 1947). A more comprehensive study is Robert Frank Futrell, Ideas, Concepts, Doctrine: Basic Thinking in the United States Air Force, 1907-1984, 2 vols. (Maxwell AFB, AL: Air University Press, 1989). On the development of air doctrine within the context of the interservice debate, see James P. Tate, The Army and Its Air Corps: Army Policy toward Aviation, 1919-1941 (Maxwell AFB, AL: Air University Press, 1988). Barry Watts, The Foundation of U.S. Air Doctrine: The Problem of Friction in War (Maxwell Air Force Base, AL: Air University Press, 1984) gives a short, but critical, analysis of the development of American airpower doctrine.
[33] Robert F. Gass, Theory, Doctrine, and Ball Bearings: Adapting Future Technology to Warfare (Ft. Leavenworth, KS: School of Advanced Military Studies, 1996), pp. 12-15.
[34] "The American observers (in England), in full knowledge of the British and German experience in the Battle of Britain, continued to place their faith in the heavily armed Flying Fortress and the Liberator, flying in great masses and in close defensive formations. Such force, in adequate mass and properly employed, they reasoned, would permit the precision daylight attacks so essential to American strategic air doctrine." Hansell, The Air Plan That Defeated Hitler, p. 33.
[35] Gass, p. 4.
[36] James P. Tate, The Army and Its Air Corps: Army Policy Toward Aviation, 1919-1941 (Maxwell AFB, AL: Air University Press, 1998), p. 158.
[37] One notable exception was Capt Claire Chennault, later commander of the Flying Tigers in China, who disagreed with the bomber invincibility theory. Ibid., pp. 161-162.
[38] Ibid., p. 159.
[39] Ibid., p. 164.
[40] Hansell, The Air Plan That Defeated Hitler, p. 57.
[41] Hallion, p. 42.
[42] For the fateful story of the Consolidated B-32, see William T. Y'Blood, "Unwanted and Unloved: The Consolidated B-32," Air Power History 42, no. 3 (Fall 1995), pp. 58-71.
[43] For a bibliographic essay covering both primary and secondary sources on the development of the B-29 and B-29 operations in the Pacific, see Ken Werrell, Blankets of Fire: U.S. Bombers Over Japan in World War II (Washington D.C.: Smithsonian Institution Press, 1996), pp. 335-341. There is no centrally-located holding of B-29 records and sources. Primary materials are maintained at various locations, including the National Archives in Washington D.C., the Air Force Historical Research Agency at Maxwell AFB, Alabama, and the Boeing Company in Seattle. Most of the key players have written their own interesting, although often biased, accounts. These memoirs include Hap Arnold's Global Mission (New York: Harper, 1949), Curtiss LeMay's Mission with LeMay (Garden City, NY: Doubleday, 1965) and Superfortress: The B-29 and American Air Power (New York: McGraw-Hill, 1988), and Haywood Hansell's Strategic Air War Against Japan (Maxwell AFB, AL: Air University, 1980). Of the three authors, Hansell's account, despite reasons to be bitter about his mistreatment, is the most detailed and thoroughly analytic. Although not as extensively covered as the strategic air war over Europe, there are numerous secondary accounts available of B-29 operations against Japan. One of the most useful works is

the official history by Wesley Craven and James Cate, The Army Air Forces in World War II (Chicago: University of Chicago, 1948-58), although at times convoluted and poorly organized. For B-29 operations, see especially volume 5. Ken Werrell's book Blankets of Fire: U.S. Bombers Over Japan in World War II is both thoroughly researched and enjoyable to read. Other worthwhile secondary works include Kevin Herbert's Maximum Effort: The B-29s Against Japan (Manhattan, KS: Sunflower University Press, 1983), E. Bartlett Kerr's Flames Over Tokyo: The U.S. Army Air Forces' Incendiary Campaign Against Japan, 1944-1945 (New York: D.I. Fine, 1991), and Conrad Crane's Bombs, Cities, and Civilians: American Airpower Strategy in World War II. (Lawrence, KS: University Press of Kansas, 1993).

[44] Spector, p. 488 ff.

[45] Werrell, p. 57

[46] Hallion, p. 44.

[47] For the story of the marriage of the Wright R-3350 engine to the B-29 Superfortress, see Robert E. Johnson, "Why the Boeing B-29 Bomber and Why the Wright R-3350 Engine," American Aviation Society Historical Journal 33, no. 3 (1988): pp. 174-189. See also Werrell, p. 68-72 and Walter J. Boyne, Clash of Wings: World War II in the Air (New York: Simon and Schuster, 1994), p. 360.

[48] Kennett, p. 166.

[49] Chester Marshall, "B-29 Superfortress" in Big Bombers of WWII (Ann Arbor, MI: Lowe & B. Hould Publishers, 1998), p. 299.

[50] Ibid., pp. 301-303. See also Werrell, pp. 195-201.

[51] Information on the defensive systems of the B-29 is from Marshall, pp. 299-301. See also David A. Anderton, B-29 Superfortress at War (New York: Scribner and Sons, 1978), pp. 24-31.

[52] Arnold, p. 158.

[53] Hansell, The Air Plan That Defeated Hitler, p. 48.

[54] Ibid., p. 54.

[55] In a report to the Chief of Staff, the Air War Plans Division boldly proclaimed, "Se Power is no longer reliable as a primary instrument of American defense. Air power must replace it as the principal means of defense." Greer, p. 113.

[56] Hansell, The Air Plan That Defeated Hitler, p. 61. See also Spector, p. 224.

[57] Werrell, pp. 49-50.

[58] Hallion, p. 43.

[59] On 17 August 1943, 60 of the 376 B-17s attacking Schweinfurt were shot down; another 27 were so badly damaged that they would never fly again; 60 others based in England but continuing on to North Africa had to be left in North Africa for extensive repairs. On 14 October, in the second Schweinfurt raid, 60 of 291 B-17s were lost with another 138 sustaining significant damage. Martin W. Bowman, USAAF Handbook 1939-1945 (Mechanisburg, PA: Stackpole Books, 1997), p. 256. For the failings of strategic bombing doctrine in Europe, see Robert F.Gass, Theory, Doctrine, and Ball Bearings: Adapting Future Technology to Warfare (Ft. Leavenworth, KS: School of Advanced Military Studies, 1996). Gass attributes the disastrous Schweinfurt bombing raids to the difficulties involved in developing theory based upon future or emerging technology.

[60] Richard G. Alexander, "Experiment in Total War," United States Naval Institute Proceedings 2, no 8 (August 1956), p. 844.

[61] Craven and Cate, pp. 13-31. The first mission by the B-29s in China on 5 June 1944 against the railroad shops in Bangkok is illustrative of the difficulties the XX Bomber Command faced. Of the 122 B-29s on hand, 10 were unavailable, 14 failed to get airborne, and another crashed just minutes after takeoff. Of the rest, 13 returned early. Weather disrupted the formation and only 77 B-29s were able to unload their bombs on their primary target. Two aircraft were forced to ditch in the Bay of Bengal due to fuel transfer problems and another two were lost. On the return to India, the aircraft were scattered from their home fields by weather and one B-29 was destroyed in a crash upon landing. Of the 353 tons of bombs released over the target, only sixteen to eighteen bombs (4 to 4.5 tons) hit in the target area. Werrell, pp. 101-102.

[62] Close, p. 13.

[63] Spector, p. 491.

[64] Hallion, pp. 44-48.

[65] Ibid., p. 45.

[66] Weigley, p. 290.

[67] B-29s required the extraordinary length of 1.5 miles of runway for a fully loaded takeoff. Lee B. Kennett, A History of Strategic Bombing (New York: Scribner, 1982), p. 166.
[68] Hallion, p. 45.
[69] Ibid., p. 50.
[70] Alexander, p. 844.
[71] Hansell, The Air Plan That Defeated Hitler, p. 211.
[72] Arnold offered Hansell a position as LeMay's deputy, but Hansell chose instead to return to the States to work with the B-29 training program. Hallion, p. 51.
[73] See Victor Davis Hanson, "The Right Man," Military History Quarterly 8, No. 3 (Spring 1996): pp. 56-65.
[74] Erich von Manstein, Lost Victories (Chicago: Henry Regnery, 1958), p. 137.
[75] See Close, p. 8 for a very detailed, yet readily understandable explanation of the high incidence of engine fires in the engines of the B-29.
[76] Hallion, p. 44.
[77] Werrell, p. 71.
[78] Ibid., p. 64.
[79] Ibid., p. 124.
[80] Ibid., p. 64.
[81] Ibid., p. 66.
[82] "HQ AAF Proving Ground Command, Final Report on Test of G.E. Fire Control Equipment in B-29 Airplane", 30 May 1944 (Historical Research Agency, 240.04-8). See also "Tests Relative to the Defense and Tactical Use of the B-29," 15 November 1944 (Air Force Historical Research Agency, 760.310-3).
[83] Locally controlled turrets were considered more accurate and more easily maintained being less technologically complex. Remotely controlled turrets made pressurization easier because of their decreased size and lack of a need for pressurization in the absence of a gunner physically manning the guns.
[84] Werrell, pp. 63-68. Werrell notes that the B-29 defensive system as originally designed was least effective against head-on attacks. To make up for this weakness, designers (after a proposal by General Kenney and several experimental projects) doubled the number of guns in the upper forward turret to four. The impact of this increased firepower was to further decrease aircraft performance and crowd the crew in the already tight forward compartment. Ibid., p. 67.
[85] Ibid., p. 155.
[86] Ibid., pp. 61-62.
[87] Ibid., pp. 123-124.
[88] Ibid., p. 92.
[89] Hallion, p. 50. See also Anderton, pp. 35-36.
[90] Hansell, p. 203.
[91] Hallion, p. 51.
[92] Spector, p. 493.
[93] Hallion, pp. 44-45. After early actions in the Pacific, Arnold complained that the Navy "had not demonstrated its ability to conduct air operations" and failed to appreciate the difficulties of logistics in the Pacific theater. Just as the Navy was unwilling to entrust the fleet to Army commanders, Arnold was unwilling to entrust air operations to the Navy. Louis Morton, "Pacific Command: A Study in Interservice Relations," in Harry Borowski, ed., The Harmon Memorial Lectures in Military History, 1959-1987 (Washington, D.C.: Office of Air Force History, 1988), p. 140.
[94] General Arnold opposed Kenney's diversion of resources from the independent strategic bombing campaign for air operations in support of the Army ground campaign. See Stanley L. Falk, "General Kenney, the Indirect Approach, and the B-29s," Aerospace History (1981): pp. 147-155. See also Thomas E. Griffith, MacArthur's Airman: General George C. Kenney and the War in the Southwest Pacific (Lawrence, KS: University of Kansas Press, 1998), pp. 147-150.
[95] Even Nimitz, in his arguments for a thrust across the Central Pacific, identified the acquisition of air bases as one of the intended purposes of the campaign. "When conflicts in timing and allocation of means exist, due weight should be accorded to the fact that operations in the Central Pacific promise at this time a more rapid advance toward Japan and her vital lines of communications; the earlier acquisition of strategic

air bases closer to the Japanese homeland; and, of greatest importance, are more likely o precipitate a decisive engagement with the Japanese fleet." Weigley, p. 285.

[96] Spector, p. 492.

[97] See Spector, pp. 489-490. Arnold, with Roosevelt's support, perhaps came closest to what each of the other services desired in the Pacific: unity of effort amongst the services under their service's command. Arnold wrote in 1942, "It becomes more and more apparent that until there is one command, one plan, one thinking head, we will continue to misuse and hold idle our air force and our army." Ibid., p. 225. Roosevelt was particularly supportive of Arnold and the leading role played by airpower. Upon the death of FDR in 1945, Arnold wrote, "Franklin Roosevelt was not only a personal friend but one of the best friends the Air Force ever had. He had supported me in the development of the Air Force and in its global operations to an extent that I little dreamed of a few years before, when I was in the doghouse. Many times he seemed more like a fellow airman than he did the Commander in Chief of all our armed forces." Arnold, pp. 548-549. See also Jeffrey S. Underwood, The Wings of Democracy: The Influence of Air Power on the Roosevelt Administration, 1933-1941 (College Station, TX: Texas A&M University Press, 1991).

[98] Morton, p. 150.

[99] Quoted in Hallion, p. 45.

[100] Ibid., p. 49.

[101] S.L.A. Marshall, Men Against Fire: The Problem of Battle Command in Future War (New York: Morrow, 1947), p. 20.

[102] Hansell, The Air Plan That Defeated Hitler, p. 30.

[103] Ibid., p. 31.

[104] For the difficulties of air intelligence in support of B-29 operations against Japan, see John F. Kreis, ed., Piercing the Fog: Intelligence and the Army Air Forces Operations in World War II (Washington, DC: Air Force History and Museums Program, 1996), pp. 329-347.

[105] Kenneth P Werrell, "The Bombing of Japan: Three New Insights," unpublished paper (Maxwell AFB, AL: Center for Aerospace Doctrine, Research and Education, 1999), pp. 3-4.

[106] See Spector, pp. 503-506.

[107] Thomas D. White, "Japan as an Objective for Air Attack," paper for the Intelligence Section, Air Corps Tactical School, Maxwell Field, AL: 1937-38 (Maxwell Air Force Base, AL: Air Force Historical Research Agency, 248.501-65B), p. 14. White's study was a detailed and well-organized analysis of the Japan's vulnerabilities to air attack. The format of the paper reportedly shaped the thoughts of the infamous airpower theorist Col John Warden and his "Five Rings", the strategy found in Operations Plan INSTANT THUNDER for the air war conducted against Iraq in 1991. Lecture, Joint Doctrine Air Campaign Course (Maxwell AFB, AL: Center for Aerospace Doctrine, Education, and Research: 29 January 1999). For the impacts of the 1923 earthquake on Japanese cities, see Jeffrey S. Underwood, The Wings of Democracy: The Influence of Air Power on the Roosevelt Administration, 1933-1941 (College Station, TX: Texas A&M University Press, 1991), p. 63.

[108] Ed Whitcomb, On Celestial Wings (Maxwell AFB, AL: Air University Press, 1995), p. 134.

[109] Billy Mitchell had also pointed to Japan's vulnerability to fire bombing in 1924. Kennett, p. 164.

[110] Kenneth P Werrell, "The Bombing of Japan: Three New Insights," p. 6. Werrell contends that LeMay was not the originator of the fire bombing attacks but instead only reluctantly adapted the ideas already forwarded by others. See also Kreis, pp. 339-342. Kreis discusses the pressures from Washington to switch from precision bombing to incendiary raids. Kreis concludes that the decision to use incendiaries against Japanese cities was "...LeMay's in form, [but] had a much different substance."

[111] Kennett, pp. 168-169.

[112] Alexander, p. 845.

[113] Haywood Hansell contends that LeMay's switch to incendiary attacks in March 1945 was directly attributable to his positive experience during the Hankow raid. See Haywood S. Hansell, Jr., The Strategic Air War Against Japan (Maxwell AFB, AL: Air University, 1980). Claire Chennault also claims that LeMay was "thoroughly impressed" by the Hankow raid. See Claire S. Chennault, Way of a Fighter (New York: Putnam, 1949), p. 330.

[114] Spector, p. 491-492. The M69 was a 6.2 pound cylindrical unit twenty inches long and three inches in diameter that trailed a cloth strip behind it to prevent tumbling and slow its descent. Upon impact, a

delayed action fuse detonated spewing flaming gasoline gel (napalm) out of the casing as far as thirty yards. Boyne, pp. 370-371.
[115] Alexander, p. 845.
[116] Twenty-two specific industrial targets were destroyed in the raid of 9-10 March 1945. 267,171 buildings, or about one fourth of all buildings in Tokyo, were destroyed. The raid killed 83,793 people, injured 40,918, and left over one million homeless. Alexander, p. 845. See also Whitcomb, p. 134.
[117] Hanson, "The Right Man," p. 60.
[118] Kennett, p. 170.
[119] Hanson, "The Right Man," p. 59.
[120] Anderton, pp. 24-25. One early analysis revealed that 45 percent of Japanese fighter attacks came from the front quarter and only 17 percent from the rear quarter. Werrell, p. 145. See also Edwin Hewitt, "Memorandum..." 23 December 1944 (Maxwell AFB, AL: Air Force Historical Research Agency, 760.310-3) and Edwin Hewitt, "Use of the B-29 Fire Control System Against Nose Attacks," 26 February 1945 (Maxwell AFB, AL: Air Force Historical Research Agency, 760.310-4).
[121] Anderton, p. 31 (see note accompanying illustration).
[122] See Edward R. Lightfoot, "Operation Workman (Staging VLR Strikes Through Iwo Jima)," 17 January 1945 (Maxwell AFB, AL: Air Force Historical Research Agency, 762.322-2) and Smith, Lotha A. "Progress Report of Plans for Utilization of 'Workman'," 1 March 1945 (Maxwell AFB, AL: Air Force Historical Research Agency, 761.322-1). See also Weigley, pp. 306-307 and Spector, pp. 494-502.
[123] Casualty figures for the Marines on Iwo Jima vary from 5000 to 6500 depending upon the source. Whitcomb, p. 136.
[124] See United States Strategic Bombing Surveys (European War) (Pacific War) Reprint (Maxwell AFB, AL: Air University Press, 1987), pp. 67-71.
[125] Craven and Cate, pp. 597-598
[126] Ibid., pp. 662-673. See also Werrell, pp. 170-177.
[127] Kennett, p. 174.
[128] Wylie, "Reflections on the War in the Pacific," pp. 360-361. See also Weigley, p. 309.
[129] After 1 March 1945, the aerial mining campaign sank or badly damaged 670 ships, including 65 combat ships. Kreis, p. 345.
[130] Werrell, pp. 202-203.
[131] Kennett, p. 174.
[132] Hallion, p. 51. Hansell discovered the availability of weather information after reading Frederick W. Winterbotham, The Ultra Secret (New York: Harper and Row, 1974). See Hansell, pp. 203-204.
[133] Werrell, pp. 146-147.
[134] Ibid., pp. 166-167.
[135] Ibid., p. 70.
[136] Close, p. 8.
[137] Werrell, p. 70.
[138] Hallion, pp. 48-49. Unfortunately, on his way back to Washington to clarify muddled command issues in the Pacific in late February 1945, Harmon's plane disappeared over the Pacific with all aboard.
[139] Craven and Cate, p. xvii.
[140] Quoted in Close, p. 44.
[141] The Navy opposed stationing the headquarters for the proposed Strategic Air Force on Guam and had disapproved an Air Force request to bring in 210,000 tons of bombs in support of the B-29 campaign against Japan. Arnold resolved both of these issues in a direct meeting with Nimitz. Thomas M. Coffey, Hap: The Story of the United States Air Force and the Man Who Built It, General Henry H. "Hap" Arnold (New York: Viking Press, 1982), p. 367.
[142] Ibid., p. 358.
[143] Werrell, p. 136.
[144] Craven and Cate, p. 577.
[145] This fearful attitude has been present throughout American military history. For example, in 1980, Franklin Spinney, a civilian defense analyst in the Pentagon, presented a report to Congress that emphasized the relationship between technological complexity and low combat readiness. Among other factors, the report attributed this consequence to reliability and maintainability issues and the "frictions of war." Its recommendations implied that, rather than innovating and adapting to these uncertainties, the

military should avoid high tech solutions in favor of less sophisticated means. See Walter Kross, "High Technology, Tactical Air Forces, and National Strategies," in Franklin D. Margiotta and Ralph Sanders, eds., Technology, Strategy and National Security (Washington, D.C.: National Defense University Press, 1985), pp. 43-76.

[146] Ralph Sanders, "Integrating Technology, Strategy, and Operational Concepts," in Franklin D. Margiotta and Ralph Sanders, eds., Technology, Strategy and National Security (Washington, D.C.: National Defense University Press, 1985), p. 160. Sanders argues that it is futile to focus on the question of whether military strategy or technology is the driving force in military affairs. Instead, "Military affairs should be viewed more accurately through a prism that reveals a complicated world characterized by many feedbacks. In such an environment one has difficulty identifying with precision any single cause and effect. ... What exists is a circular chain reaction in which suggestions and demands, originating both in the world of the technologist and of the military strategist or operator continually bump against each other. Perceived operational needs trigger technological developments, which in turn produce other technological needs or opportunities, which again affect the way people think about war. ...The important point is that... an untidy situation exists in which action, reaction, and counteraction produce a maze of relationships. In these relationships both technologists and designers of operational concepts confront uncertainty." Ibid., pp. 160-161.

[147] For German adaptations to the Allied strategic air campaign, see Luttwak, pp. 26-31.

[148] Werrell, p. 191. Werrell discusses several of the radar countermeasures, including both chaff and jamming, developed for the B-29 against Japanese radar and radar directed searchlights. The result of these countermeasures was that the Japanese simply turned off their defensive radars once B-29 jamming began. One estimate credits the countermeasure campaign with saving two hundred B-29s. Ibid., pp. 191-192.

[149] Losses from Japanese defensive adaptations did rise late in 1944 but overall were never as significant as losses in the European theater. Throughout the war, losses to operational causes exceeded losses to enemy actions. Japanese fighter forces made their heaviest impact in January 1945 when B-29 losses rose to 5.7 percent. Kennett, pp. 173-174. For an interesting account of a Japanese mock-up of a B-29 used to train kamikaze pilots attacking American airfields, see Robert C. Mikesh, "B-29 Made in Japan," American Aviation Society Historical Journal 41, no. 4 (1996): 296-299

[150] Kennett, p. 175. See also Werrell, pp. 177-179 and Boyne, p. 373. For LeMay's comments on the futility of bombing airfields to eliminate kamikaze attacks and the time wasted in the effort, see Richard H. Kohn and Joseph P. Harahan, eds., Strategic Air Warfare (Washington, DC: Office of Air Force History, 1988), pp. 47-52.

[151] Werrell, p. 176.

[152] Alexander, p. 846. See Bradford Laws, "Directive Carried Out," 1945 (Maxwell AFB, AL: Air Force Historical Research Agency, 760.01) for the 20th Air Force post-war media release on the accomplishments of the B-29 over Japan. See also Office of Statistical Control, "Summary of 20th Air Force Operations, 5 June 1944 – 14 August 1945," 1 October 1945 (Ft. Leavenworth, KS: Combined Arms Research Library, R-11628).

Appendix I: Timeline of Events

January 1940	Army Air Corps design requirement for VLR bomber
21 September 1942	First Boeing XB-29 flown in Seattle
4 April 1944	Twentieth Air Force activated in the Pacific
5 June 1944	First XX Bomber Command mission from China; first B-29 mission of the war
June – August 1944	Guam, Tinian, and Saipan in the Marianas secured for B-29 operations
15 June 1944	First B-29 mission against mainland Japan from China
12 October 1944	First B-29 arrives in Saipan
1 November 1944	First B-29 reconnaissance mission over Japan from Saipan
24 November 1944	First B-29 raid on Tokyo from the Marianas
20 January 1945	LeMay replaces Hansell as Commander, XXI Bomber Command
25 February 1945	Experimental low-level incendiary raids against Tokyo
4 March 1945	First B-29 emergency landing on Iwo Jima
9-10 March 1945	Full-scale incendiary attack against Tokyo
April – May 1945	B-29s operate in support of Okinawa invasion
July 1944	Headquarters, Twentieth Air Force transferred from the U.S. to Guam
16 July 1945	Gen. Carl Spaatz assumes command of the newly created U.S. Army Strategic Air Force
6 August 1945	First atomic bomb dropped by a B-29 on Hiroshima
9 August 1945	Second atomic bomb dropped on Nagasaki
14 August 1945	A record 809 B-29s bomb targets in Japan; Japanese government surrenders

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